



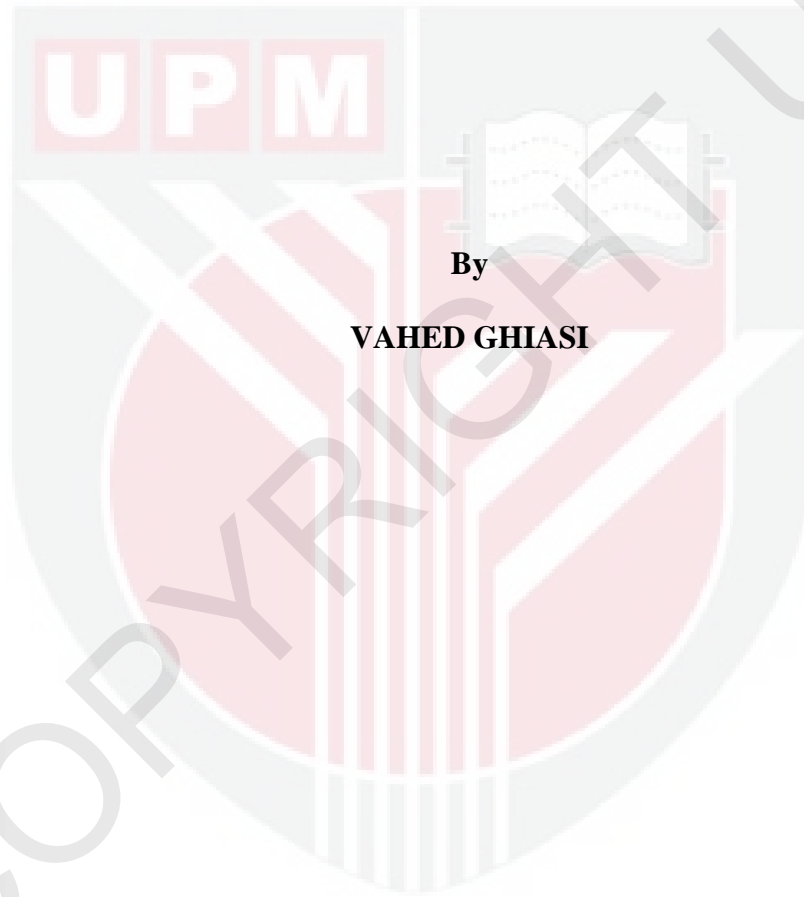
UNIVERSITI PUTRA MALAYSIA

***EFFECTS OF WEAK ROCK GEOMECHANICAL PROPERTIES ON
TUNNEL STABILITY***

VAHED GHIASI

FK 2012 116

**EFFECTS OF WEAK ROCK GEOMECHANICAL PROPERTIES ON
TUNNEL STABILITY**



By

VAHED GHIASI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

January 2012

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

**EFFECTS OF WEAK ROCK GEOMECHANICAL PROPERTIES ON
TUNNEL STABILITY**

By

VAHED GHIASI

January 2012

Chairman : Professor Husaini Omar, PhD

Faculty : Engineering

Numerous tunnels are constructed in various parts of the world. Various technologies such as the Tunneling Boring Machine (TBM), New Austrian Tunneling Method (NATM), cut and cover method, and drilling and blasting method are used in order to aid tunnel constructions. In order to investigate the behavior of tunnels and to enhance these technologies, it is primarily important to investigate the issues pertaining to the soil and rock structure interaction. It is also of prime importance to study their impact on the tunnel system's performance. In engineering practice, geotechnical problems such as settlement and ground stability are not given due consideration in tunnel crossing constructions on the ground surface in urban areas. In order to deal with the challenges of geotechnology, full scale experiments may be performed. However it may not be feasible to conduct full scale experiments as it may be expensive.

The main purpose of this thesis is to evaluate the ground behavior in terms of deformation and strength parameters related to tunnel stability in different geomaterials such as weak rocks. This thesis has contributed vastly towards the understanding of the effects of tunnel structures on the geomaterials surrounding the tunnel and interaction between them. The main methods employed in this thesis are based on desk studies (theoretical investigation), laboratory tests, field investigations and the use of computer softwares. Advanced constitutive models were used in geometrical applications for numerical simulation of linear and non-linear, time-dependent and anisotropic behavior of soil and weak rocks. Unique procedures are required in order to deal with hydrostatic and non-hydrostatic pore pressures. These are needed as soil and rock are multi-phase materials. Although the modeling of the soil and rock itself is an important issue, many tunnel projects involve the modeling of structures and the interaction between the structures and the soil and rock. Numerical simulations with the Finite Element Method (FEM) and Finite Deferential Method (FDM) were conducted to analyze in order to evaluate the influence of stress on displacement and other factors in the process.

It is of prime importance to identify the mechanical properties of rock and soil. This is significant to assess the stability of tunnels as the design of support system is one of the most important steps in tunneling. Lack of knowledge of geo-mechanical and physical properties such as the mechanical behavior of the materials surrounding the underground or surface structure would make it impossible to offer suitable supervision, propose methods for an appropriate design, or predict risks with a reasonable degree of accuracy.

The current thesis contributes in various ways to enhance existing knowledge. Some of the significant areas are (i) the plan which has been developed for the design of tunnels; the plan for tunnel design and studding in rocks which contains the theoretical, and experimental investigations, including charts and graphs, of Karaj and North Water Convey Tunnel (NWCT) path and its stability analysis in Iran and electrified double track tunnel project between Ipoh and Padang Besar which is the longest rail tunnel project in Malaysia (ii) Evaluation of the squeezing potential of tunnels is presented in this thesis with significant results, (iii) Proposed method for evaluation of squeezing potential in rock tunnel which is Tunnel Instability Ranking(TIR), (iv) using numerical methods (FEM and FDM) to analyze the management of stability and hazards in tunnel construction. Another contribution is the studies regarding the modulus of elasticity and compressive strength in weathered granite, which is related to tunnel stability.

The results derived from the analysis indicate that tunnels in faulted regions are unstable and it is crucial to provide strong supports in these regions. The studies on the strength parameters and grain size of weathered granites revealed trends that show strength increases with decreasing grain size. It has been noted that with increased weathering, the modulus of elasticity decreases linearly with a decreasing uniaxial compressive strength.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai
mementuhi keperluan untuk ijazah Doktor Falsafah

**KESAN-KESAN GEOMEKANIKAL BATUAN LEMAH TERHADAP
KESTABILAN TEROWONG**

Oleh

VAHED GHIASI

Januari 2012

Pengerusi : Profesor Husaini Bin Omar, PhD

Fakulti : Kejuruteraan

Terdapat banyak pembinaan terowong yang dibina di seluruh dunia. Pelbagai teknologi seperti " Tunneling Boring Machine" (TBM), "New Austrian Tunneling Method (NATM)", "Cut and Cover Method", menggerudi dan menggunakan bahan letupan digunakan untuk membantu dalam pembinaan terowong. Untuk menyiasat kelakuan terowong dan untuk menambahbaik teknologi tersebut, adalah sangat penting untuk mengkaji isu yang berkaitan tanah dan struktur batuan Dalam amalan kejuruteraan, masalah geoteknikal seperti pemendapan dan kestabilan permukaan tanah tidak diberikan keutamaan yang sewajarnya dalam pembinaan terowong lintasan bersilang di kawasan bandar. Dalam mengatasi cabaran geoteknologi, eksperimen menyeluruh perlu dijalankan. Walaubagaimanapun kaedah ini mungkin tidak boleh dijalankan kerana projek ini memerlukan kos yang tinggi.

Tujuan utama tesis ini dijalankan adalah untuk menilai sifat permukaan tanah dari segi ubahbentuk dan kekuatan yang merupakan parameter yang berkait rapat dengan kestabilan terowong yang berbeza dari segi geobahan seperti batuan lemah. Tesis ini telah banyak menyumbang kepada cara memahami kesan dan tindakan geobahan keatas struktur keseluruhan terowong. Kaedah utama yang digunakan dalam tesis ini adalah berdasarkan kajian meja, ujian makmal, penyiataan lapangan dan penggunaan perisian komputer. Model konstitutif lanjutan dibuat menggunakan aplikasi geometrical untuk proses simulasi numerikal untuk linear, bukan linear, pengaruh masa, dan sifat anisotropic tanah dan batuan lemah. Prosedur yang unik diperlukan untuk menangani hidostatik dan bukan hidrostatik terhadap tekanan liang. Prosedur ini diperlukan kerana tanah dan batuan adalah bahan berbilang fasa.. Walaupun model tanah dan butuan ini adalah satu isu yang penting, banyak projek pembinaan terowong melibatkan permodelan struktur dan interaksi struktur tanah dan batuan. Simulasi numerikal dengan menggunakan kaedah unsure terhingga (FEM) dan kaedah kebedaan terhingga(FDM) telah dijalankan untuk mengkaji terowong berkenaan dalam mengenalpasti kesan yang dihasilkan terhadap tekanan anjakan dan factor lain dalam proses ini.

Asas utama dalam proses ini adalah untuk mengenal pasti sifat mekanikal butuan dan tanah. Ini penting dalam menentukan kestabilan dan rekaan system sokongan .. Pengetahuan yang kurang dalam memahami geomekanikal dan kualiti fizikal seperti sifat mekanikal di sekeliling bawan permkaan atau permukaan menyebabkan susah untuk menawarkan penyeliaan kaedah yang sesuai.

Sumbangan tesis ini adalah dalam pelbagai cara untuk meningkatkan pengetahuan yang sedia ada. Sesetengah daripada kawasan projek terutamanya: 1) rancangan untuk membangunkan rekabentuk terowong; merancang untuk mereka bentuk terowong dan mencengkam batu yang telah dikaji secara teori dan melalui eksperimen termasuklah carta dan graf dalam mengkaji geomekanikal jism batu Karaj dan 'North Water Convey Tunnel' (NWCT) dan analisis kestabilan di Iran dan projek pembinaan landasan berkembar terowong elektrik antara Ipoh dan Padang Besar yang merupakan projek rel terowong terpanjang di Malaysia. 2) Penilaian potensi untuk mengecilkan/ mengubah bentuk terowong yang dikemukakan dalam tesis ini bersama keputusan yang nyata. 3) mencadangkan kaedah untuk menilai potensi untuk mengecilkan / mengubah bentuk terowong batu yang merupakan gred ketidakstabilan terowong / Tunnel Instability Ranking (TIR), 4) menggunakan kaedah numerikal (FEM and FDM) untuk menganalisis cara pengurusan kestabilan dan risiko dalam pembinaan terowong. Antara sumbangan lain adalah mengenai modulus/ unit keanjalan dan kekuatan mampatan dalam mengubah bentuk granit/ batu keras yang berkait rapat dengan kestabilan pembinaan terowong.

Keputusan yang dikeluarkan dari analisis ini menunjukkan terowong di kawasan yang mempunyai sesar adalah tidak stabil dan adalah penting untuk memberi sokongan yang teguh di kawasan ini.

Kajian terhadap batuan granit terluluhawa bergantung kepada parameter-parameter kekuatan dan saiz butiran granit / batu keras, modulus keanjalan berkadar secara linear dengan mengurangkan kekuatan mampatan unipaksi.

DEDICATION

This work is dedicated to my family members
who are always giving me encouragement
and support.



ACKNOWLEDGEMENTS

First of all I should thank the Almighty, for without His blessings it would not have been possible for me to do this study. Special thanks to Prof. Ir. Dr. Husaini Omar, who besides being my supervisor, tirelessly worked hard to ensure that I managed to complete study. His commitment all through my studies was overwhelming. I would also like to thank my other supervisory committee members, Prof. Ir. Dr. Bujang Bin Kim Huat and Prof. Dr. Ratnasamy Muniandy for their guidance and advice whenever I encountered problems in the course of my research. I would like to thank Prof. Nick Barton from Norwegian Geotechnical Institute (NGI) and Prof. Jamal Rostami from Pennsylvania State University (PSU) for their helpful comments and encouragement to present this work. I would like to thank the Director of the Mountainous Develop Center Research Center (MTD-RC) Universiti Putra Malaysia and financial support received from Research and Innovation Center Fellowship (GRF).

The last but not the least, I owe my thanks to my mother Tajdulat Souri, my father Hatam Ghiasi and my brother Samad Ghiasi for their support, understanding, help and encouragement.

Thank you MALAYSIA.

Vahed Ghiasi

10 Aug 2011

I certify that an Examination Committee has met on to conduct the final examination of **Vahed Ghiasi** on his **Doctor of Philosophy** thesis entitled “**EFFECT OF WEAK ROCK GEOMECHANICAL PROPERTIES ON TUNNEL STABILITY**” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Abang Abdullah Bin Abang Mohamad Ali, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Zainuddin Bin Mohamad. Yusoff , PhD

Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Habil Biswajeet Pradhan, PhD

Professor
Institute of Advanced Technology
Universiti Putra Malaysia
(Internal Examiner)

Vernon Ray Schaefer, PhD

Professor
Department of Civil, Construction and Environmental Engineering
Ames, Iowa State University of Science and Technology
USA
(External Examiner)

SEOW HENG FONG, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 30 January 2012

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Husaini Bin Omar, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Bujang Bin Kim Huat, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ratnasamy Muniandy, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

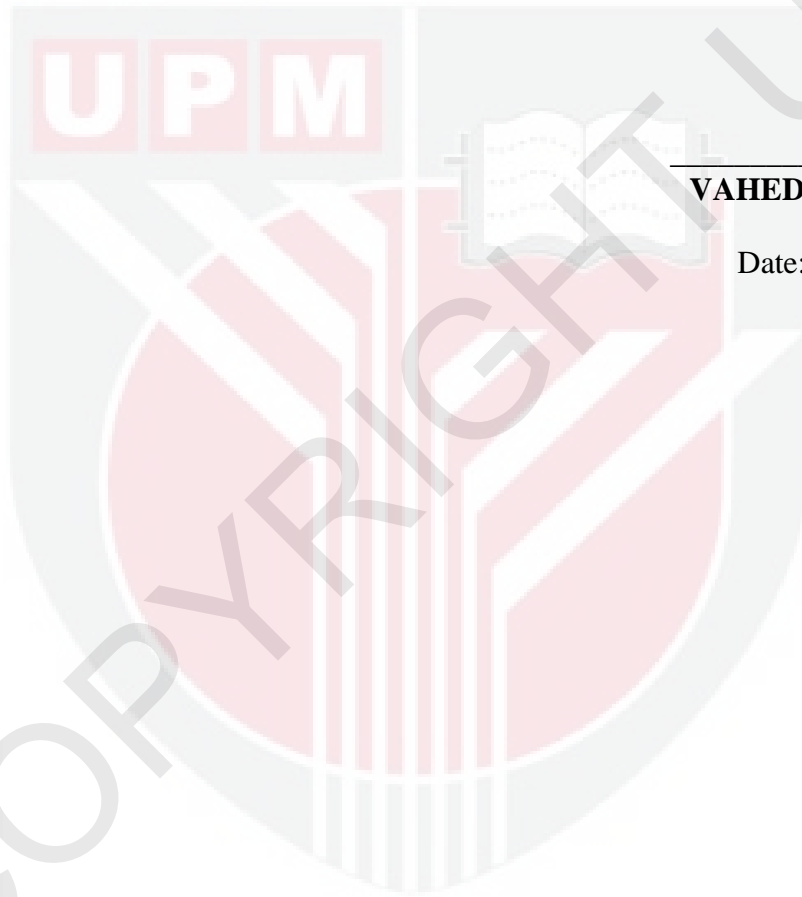
BUJANG BIN KIM HUAT, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 21 June 2012

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, or is not concurrently, submitted for any other degree at University Putra Malaysia or at any other institution.



VAHED GHIASI

Date:

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	v
ACKNOWLEDGEMENTS	ix
APPROVAL	x
DECLARATION	xii
LIST OF TABLES	xvii
LIST OF FIGURES	xxi
LIST OF ABBREVIATIONS	xxx
CHAPTER	
1 INTRODUCTION	1
1.1 General	1
1.2 Problem Statement	5
1.3 Research Aims and Objectives	11
1.4 Scope and Limitation	11
1.5 Significance of the Study	12
1.6 Thesis Organization	12
2 LITERATURE REVIEW	14
2.1 Introduction	14
2.2 Studies on the Weathering Granite	16
2.3 Stability Analysis of Tunnels Using Numerical Modeling	22
2.3.1 Numerical Analyses	26
2.3.2 Different Methods Used in Solving the Tunnel Problems	31
2.3.3 The Application of Numerical Modeling in Tunnel	33
2.3.4 Finite Element Method (FEM)	36
2.3.5 Finite Difference Method(FDM)	37
2.3.6 Beam Element Method with Elastic Support	38
2.4 Urban Tunneling Challenges and Risk Management	39
2.4.1 Definitions of Main Concepts of Risk in Tunnel	40
2.4.2 Geotechnical Risk Management	42
2.4.3 Urban Tunneling Challenges and Hazard	45
2.4.4 General Trends in the Tunneling Industry	46
2.4.5 Hazards of Tunneling	46
2.4.6 Consequences for the Insurance Industry	52
2.4.7 Ground Tunnel Interaction	54
2.4.8 Geomaterial Tunneling	54
2.5 Tunneling in Malaysia	54
2.6 Assessment of Tunnels under Squeezing Rock Conditions	58

2.6.1	Identification and Quantification of Squeezing Conditions	60
2.6.2	Empirical Approaches	62
2.6.3	Semi-Empirical Approaches	66
2.7	Critical Summery	78
2.8	Summary of Review	80
3	MATERIAL AND METHODS	83
3.1	Introduction	83
3.1.1	Main Goals of Engineering Geological Investigations	89
3.1.2	Rock Core Sampling	90
3.1.3	Description of Rock in Exploratory Drilling	92
3.1.4	Rock Sample Preservation and Shipment	93
3.1.5	Laboratory Rock Testing	94
3.1.6	Physical Property Testing for Rocks	94
3.1.7	Monitoring Systems	96
3.2	Studies on the Weathering Granite	100
3.2.1	Laboratory Work and Testing Procedures	104
3.3	Bukit Berapit and Larut Tunnels – Malaysian Experience	108
3.3.1	General Tunnel Layout	108
3.3.2	Geological Settings of Berapit and Larut Tunnels	110
3.3.3	Excavation Techniques	113
3.4	Geomechanical Investigation of the Rock Mass of the Karaj Tunnel	114
3.4.1	Geological Conditions	117
3.4.2	Identification of Engineering Geology Units in Study Area	120
3.4.3	Proposed method, Tunnel Instability Ranking (TIR)	120
3.5	Geotechnical and Geological Studies of NWCT	124
3.5.1	Geological Conditions	126
3.6	Stability Analysis and Numerical Methods	131
3.6.1	Numerical Modeling Software	131
3.6.2	Roles of Numerical (FEM, FDM) Methods in Tunnel Design	134
3.6.3	Role of Experimental Methods in Tunnel Design	136
3.6.4	Validation and Verification of Result in Tunnel Design	136
3.7	Summary	137
4	RESULT AND DISCUSSION	138
4.1	Introduction	138
4.2	Study of Weathered Rock	138
4.3	Designing of Designing Electrified Double Track Tunnel	141
4.3.1	Synthesis of Geomechanical Characterization	141
4.3.2	Design Criteria and Choice of the Stabilization Measures	145
4.3.3	Geomechanical Behaviour Categories of Sections	145

4.3.4	Dimensioning and Verifications of Primary Support	148
4.3.5	Primary Support Verification	150
4.3.6	Verification of the Umbrella Arch	151
4.3.7	Monitoring and Counter-Measures	153
4.4	Geomechanical Investigation of Rock Mass of Karaj Tunnel	157
4.4.1	Important Geomechanical Properties of Discontinuities	162
4.4.2	Engineering Classification of Rock Masses	168
4.4.3	Determination Mass Rock Strength Parameters	173
4.4.4	Rock Mass Parameters	177
4.4.5	Strength of Rock Mass	179
4.4.6	Deformation Modulus of Rock Mass (E_{mass})	181
4.4.7	In-Situ Stresses	185
4.4.8	Evaluation of Squeezing Conditions	186
4.4.9	Support Pressure	189
4.4.10	Tunnel Support Assessment	192
4.4.11	Empirical Methods	192
4.5	Geotechnical and Geological Studies of NWCT	195
4.5.1	Engineering Classification of Rock Mass	199
4.5.2	Rock Mass Parameters	201
4.5.3	Strength of Rock Mass	207
4.5.4	Deformation Modulus of Rock Mass (E_{mass})	209
4.5.5	Evaluation of Squeezing Conditions	210
4.5.6	Support Pressures	211
4.5.7	Empirical Methods	212
4.5.8	Discussion	214
4.6	Evaluation of Squeezing in Two Case Studies	218
4.7	Stability Analysis and Numerical Methods	219
4.7.1	Designing of Tunnel	222
4.7.2	Tunnel with 20-30m Depth	223
4.7.3	Assumption in Numerical Methods	233
4.7.4	Verification of Results	233
4.8	Summary of Contribution	236
4.8.1	Rock Classification Method (RCM)	236
4.8.2	Tunnel Instability Ranking (TIR)	237
5	CONCLUSIONS AND RECOMANDATIONS	240
5.1	Summary	240
5.2	Major Findings	241
5.2.1	Evaluation Geomechanical Properties	241
5.2.2	Field and Laboratory Investigation of Weak Rocks (Electrified Double Track Tunnel)	241
5.2.3	Field and Laboratory Investigation of Weak Rocks (Karaj Tunnel)	242
5.2.4	Field and Laboratory Investigation of Weak Rocks (NWCT)	243
5.2.5	Prediction Failure Potential and Evaluation Behavior of Tunnels	244

5.2.6	Development New Method of Tunnel Stability Analysis under Squeezing Rock Conditions	245
5.3	Future Studies	248
	REFERENCES	250
	APPENDIX	262
	BIODATA OF STUDENT	322
	LIST OF PUBLICATION	323

